REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-06-0157

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	
30-09--2005	Final Report	July 1,2003 to June 30,

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
First Look at Important Issues in System Architecture	
	5b. GRANT NUMBER
	F49620-03-1-0238
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
Peter P. Chen	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPOR NUMBER
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9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
AFOSR	
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT

System architecture has emerged as one of the most important areas of research for the Air Force. Many past system failures or problems can be attributed to improper system architectures or even no architecture at all. It is very critical to identify a set of important research topics in this area so that researchers and funding agencies can focus their attention to these topics to make the research investments most effective and to produce the research results that can benefit the Air Force most.

This report summarized the research project which identified several important research issues after extensive research and discussions with experts and specialists. We believe investments on these important research directions will great enhance Air Force's capabilities in acquisition, design, and implementation of future generations of systems. These important issues are: a new mathematical framework and operators of system architecture, practical applications of system architecture, and whether it is feasibl to adopt the "wind tunnel" concept to system architecture.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

1. cover page

(Final Report)

First Look at Important Issues in System Architecture

Agreement Number: AFOSR No. F49620-03-1-0238
Performance Period: 7/1/03 – 6/30/05

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September 2005

20060601086

2. Objective

A system consists of components, which could be systems themselves. Sometimes, different ways of linking the components together may produce systems with different behavior and properties. In the past, many projects were delayed or designed incorrectly because of lack of understanding of system architecture. In building large-scale systems (information systems and non-information systems) in the past twenty years, mos organizations (no matter they are in the military/government domain or in the private domains) became recognized the importance of system architecture. The objective of the project is to identify the state of art in system architecture.

3. Status of the Effort

The project has completed, and we have identified several important research issues in system architecture. These important issues are: a new mathematical framework and operators of system architecture, practical applications of system architecture, and whether it is feasible to adopt the "wind tunnel" concept to system architecture.

4. Accomplishments and New Findings: Key Research Topics Identified and recommended

There are many research issues in the system architecture area. We believe the following research areas will bring significant benefits to the Air Force:

(1) Mathematical Foundation of System Architecture

It is well recognized that there is a very strong need for more precise definitions and specifications of systems using mathematical (particularly, the algebraic) formalism. The PI of this proposal has been working on a set c algebraic operators that will be suitable for systems specifications, analysis and evaluation. Some preliminary results have been presented at the New Orleans System Architecture Workshop (1/2004) and the MIT Symposium on System Theory (3/2004). Specifically, the PI has proposed an algebraic system that consists of the following major ingredients:

- Three Types of Sets
  - Entity Sets, Relationship Sets, and Value Sets
  - Relationship is a "mathematical relation" defined on a Cartesian Products of Entity Sets
  - Attributes are "mappings/math. relations"
- A Set of Algebraic Operators
  - Operations on Entity Sets
  - Operations on Relationship Sets
  - Operations on Value Sets
- Innovative/New Features
  - Operators have "cost functions," "time duration function," "pre-conditions," "after-conditions," etc.

Examples of the algebraic operations are:
- Composition of relationships:
  - Parents (Parents (x: person))
    = grandparent (x: person)
- Construction of a high-level entity (i.e., assembly) from several low-level entities (components):
  - W = Construct ([x, y, z,...], where x, y, z are ... and cost functions, conditions, constraints)
- Deletion of Relationship
- Addition of Relationship
- Move an entity = break up relationship(s) and addition of (new) relationship(s)

A simplified version of the algebraic operations was discussed and used in the analysis of a certain family of tree/hierarchical structures for the study of complexity and the optimal structure of an organization, and this paper is attached at the end of the cost proposal.

We believe this type of analysis will be useful in the analysis and evaluation of alternative system architectures

(2) <u>Practical applications of system architecture</u>:
We believe that research should be performed on the following research questions such as: Is the architecture logically correct?, Does the architecture exhibit the desired behavior?, Do instantiations of this architecture exhibit the desired performance characteristics?, Do systems built in conformance to this architecture provide the desired capability?, Can we analyze alternatives?, Is the architecture logically correct?, and other questions.

In addition to these practical application issues, we think that research should be performed on how to apply the algebraic operators (developed in Task#1) to one or mroe selected systems of interest to the Air Force. Fo example, it seems to be possible to specify many concepts and operations of Cyber Information Assurance in algebraic operations. For example, we may specify that information security is an aggregation of security polic and procedures, confidentiality, availability, physical security, awareness, execution, training, and other factors

Information Security = **Aggregation** (Security Policy and Procedures, Confidentiality, Availability, Physical Security, Awareness, Execution, Training, Other Factors).

Cyber Command and Control (C2) Center is a brand new area of research within the DoD. Almost no work ha been done on the system architecture of Cyber C2 Center, not to mention a formal and mathematical specification of Cyber C2 Center. If we can produce some good research results (i.e., more detailed specifications like the formula given above) or even identification of major research issues on this topic in the near future, that will be a significant accomplishment for the AFRL/IF and will be very beneficial to AF and DoD in the design and implementation of Cyber C2 Center in the future.

(3) <u>Feasibility of Adopting the "Wind Tunnel" Concept to System Architecture</u>:
Recently, the same concerns of system architecture problems are reiterated in a briefing by the AF SAB to Dr Tom Cruise, current AF Chief Scientist, titled "C2 Wind Tunnels". The basic aim of the wind tunnel concept is to develop a test capability that can evaluate all C2 designs, develop an environment for demonstrating scale models, and provide for demonstrations of systems-level performance with high granularity. Can we adopt the wind tunnel concept to information systems architecture? If so, how to do it?

(4) <u>Other Research Directions</u>
Some of other future research directions include:
- To strengthen further the theoretical foundation of system architecture
- To develop methodologies and tools for system architects and designers to use in the design, implementation, and evaluation of alternative system architecture and designs.

5. Personnel Supported:
Peter Chen (faculty), student assistants, and a consultant (Dr. Joel Moses of MIT).

6. Publications
6. 1. Journal Publications
Peter Chen and Guoli Ding, "The Best Expert vs. the Smartest Algorithm", Theoretical Computer Science, Vol. 324, No. 2-3, (2004), pp. 361-380.

S. Seiden, P. Chen, R. Lax, J. Chen, G. Ding , "New Bounds for Randomized Busing", Theoretical Computer Science, Vol. 332, No. 1-3, (2005), pp. 63-81.

Peter Chen, Guoli Ding, "A Note on the Complexity of Rooted Tree and Hierarchies with Possible Applications to Organization Design and System Architecture", Transactions on Applied Mathematics, Accepted

Min Song, Il-Yeol Song, and Peter Chen, "Design and Development of a Cross Search Engine for Multiple Heterogeneous Databases Using UML and Design Patterns", International Journal of Information System Frontiers, p. 77, vol. 6, (2004).

Ding, G., and Chen, P.P., "Unavoidable Double-Connected Large Graphs", Discrete Mathematics, Volume 28C Issues 1-3, (6 April 2004), pp. 1-12.

6. 2. Books or Other One-time Publications
Peter Chen, "Toward A Structured Icon Design Methodology", (2003). Conference Proceedings, Published Bibliography: Proceedings of IEEE Conference on Multimedia Software Engineering (MSE03)

Peter P. Chen, "Architecture for Information Assurance Decision Support based on Knowledge Intensive Multi-agent Systems", (2003). Conference Proceedings, Published Bibliography: Proc. IEEE International Conference on Integration of Knowledge Intensive Multi-Agent Systems

Jianhua Chen, et. al., "Induction and Inference with Fuzzy Rules in Textual Information Retrieval", (2004). Boo Chapter, Published Editor(s): E. Triantaphillou and G. Felici Collection: Data Mining and Knowledge Discovery Techniques based on Rule Induction Techniques Bibliography: Kluwer Academic Publishers

Peter P. Chen, "A Note on the Complexity of Rooted Tree and Hierarchies with Possible Applications to Organization Design and System Architecture", (2005). Conference Proceedings, Accepted Bibliography: Proceedings of Conference on applied Mathematics

L. Moscovich and Jianhua Chen, "Supervised Hidden Markov Model Learning using the State Distribution Oracle", ( ). Conference Proceedings, Submitted Bibliography: Conference on Machine Learning

J. Chen, P. Chen, G. Ding, R. Lax, "A New Method of Learning Pseudo-Boolean Function with Applications in Terrorist Profiling and Predictions", (2004). Conference Proceedgins, Published Bibliography: IEEE Conferenc on Cybernetics

Nigel Gwee and Peter Chen, "THE WHOLE GREATER THAN THE SUM OF ITS PARTS: COMBINING THE STRENGTHS OF HEURISTIC OPTIMIZATION ALGORITHMS ", (2004). Conference Proceedings, Published Bibliography: IEEE Conference on Cybernetics

7. Interactions

The PI and several students organized the system architecture workshop held in New Orleans in January 2004, which provided a forum for researchers and practitioners to interact with each others. Besides this workshop, the PI also attended several conferences and workshops and exchanged ideas with other researchers and practitioners.

8. New discoveries, inventions, or patent disclosures
(None)

9. Honors and Awards
9.1. Before this grant was awarded
- Listed in **Who's Who in America**, 1989-now
- Listed in **Who's Who in the World**, 1990-now.
- **IEEE Harry Goode Award**, IEEE Computer Society, 2002. Previous recipients include pioneers in computer (**Aiken, Stibitz, Zuse, Eckert, Mauchly,** and **Wilkes**), magnetic memory (**Forrester**), semiconductor and INTEL Corp. (**Moore** and **Noyce**), and IBM compatible mainframes (**Amdahl**), not to mention other very distinguished scientists.
- **Recognized as one of 16 "Software Pioneers,"** at the **Software Pioneers Conference**, June 28/29, 2001, Bonn, Germany. Other software pioneers include: **Fred Brooks, E. Dijkstra, T. Hoare, D. Parnas, N. Wirth, Ole-Johan Dahl, K. Nyaard, and Alan Kay**. Some of these Software Pioneers are either National Medal of Technology winners, ACM Turing Award winners, or IEEE Harry Goode Award winners.
- **Information Technology Award**, Data Admin. Mgmt Association (NY), 1990.
- **Year 2000 Achievement Award**, DAMA International, 2000. Dr. **E. F. Codd** (the inventor of the Relational model and an ACM Turing Award winner) was the recipient of this award in 2001.
- **Inductee, Data Management Hall of Fame**, 2000.
- **Stevens Award in Software Method Innovation**, 2001.
- **Fellow, IEEE** (Institute of Electrical and Electronic Engineers), elected 1987.
- **Fellow, ACM** (Association of Computing Machinery), elected 1997.
- **Fellow, AAAS** (American Association of Advancement of Sciences), Elected 1999.
- **Member, European Academy of Sciences**, Elected 2002.
- **Distinguished Faculty Award**, LSU, 2005.
- **Invited Expert**, several working groups, **World Wide Web Consortium (W3C)**, 1999 - now.
- IEEE Computer Society **Certification of Appreciation**, 1984.
- **Career Development Award**, UCLA, 1979; **Harvard University Fellowship**, 1969.
- **First Place**, National Competition of Studying-Abroad Scholarships, Taiwan, 1969.

9. 2. After the time this grant was awarded
- **ACM/AAAI Allen Newell Award,** 2003. The past recipients are: **Brooks** (winner of National Medal of Technology and Turing Award), **Lederberg** (winner of **Nobel Prize** and National Medal of Science), **Mead** (winner of National Medal of Technology), **Amarel, Leveson, Zadeh**, and **Bajcsy**.
- **2004 Pan Wen-Yuan Outstanding Research Award**, Taiwan (each year given to one individual in the high tech fields and residing outside of Taiwan and China). The 2003 Winner was **Andrew C.C. Yao** (an ACM Turing Award winner).
- **Member, Advisory Board, National Science Foundation, Computer and Information Sciences Directorate (NSF/CISE)**, July 2004 - Now.
- **Member, Air Force Scientific Advisory Board (AF-SAB)**, 2005-Now.